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Recolonisation patterns of orthopteran species in successional stages of revegetated coal mine sites

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Abstract

The diversity and abundance of insects belonging to the order Orthoptera was studied in coal mine spoils of different ages (0- 10 year old) located in Singrauli and the adjoining border area between Uttar Pradesh and Madhya Pradesh in India. The abundance of the 21 orthopteran species (belonging to 16 genera) showed significant variations in 0-8 year old mine sites relative to the 10 year old reference site. Orthopteran alpha diversity increased sharply in the 2 year old site. The gradual increase in alpha diversity in the 4-10 year old sites did not demonstrate any significant differences. However, abundance and number of grasshopper species showed a clear linear increase with increase with mine site rehabilitation. Overlap in orthopteran rank abundance curves obtained for 4-10 year old sites is probably due to differences in the occurrence, abundance and diversity patterns of grasshopper and cricket species with increase in mine site rehabilitation age. Our results demonstrate that grasshopper species assemblages are highly sensitive to variations in the level of anthropogenically-caused disturbance, due to mining activities. Thus, the abundance patterns of grasshoppers, including those of habitat specialists, may be of significance in evaluation of the restoration progress in degraded ecosystems, such as mine sites.

Keywords: *Grasshoppers, insect diversity, degraded ecosystems, recolonisation patterns.*

Introduction

Anthropogenically-caused environmental degradation and the consequent adverse impact on biodiversity are of worldwide concern (Bengtsson *et al.*, 2000; Folke *et al.*, 2004; Dornelas, 2010). The restoration of degraded lands such as mine sites is a priority area in conservation biology (see recent review by Suding, 2011), since mine spoils (the piles of accumulated over-burden excavated during the mining process) cause ecosystem degradation by destruction of flora and fauna. Though succession and recolonisation by vegetation and vertebrate wildlife on reclaimed mine lands has been studied (Majer, 1989), diversity patterns of early colonising invertebrate species needs greater attention since they play a vital role in the re-establishment of a functioning ecosystem (Majer, 2009).

Arthropods are found to occupy a wide diversity of microhabitats and niches. Moreover, they play more diverse ecological roles than any other group of animals. Their short generation times and their small size makes arthropods, particularly insects, ideal organisms for monitoring spatial and temporal changes in habitat quality and restoration success (Longcore, 2003). Hence, among the mine site fauna, insects need to be targeted for assessment of the recolonising patterns.

In revegetated mines, the colonising patterns of insect herbivores assume special significance, since these may influence ecosystem succession via herbivory and may also reflect the rehabilitation process. Insects belonging to the order Orthoptera play a critical role in grassland ecosystems, since they constitute the major proportion of arthropod biomass (Shure and Phillips, 1991). Grasshopper assemblages appear to play the main roles in forming and maintaining the biodiversity and the stability of various kinds of grassland ecosystems (Guo *et al.*, 2006). Moreover, orthopteran nymphs are highly mobile (Floren *et al.*, 2001), allowing orthopteran communities to closely follow plant communities with progressive adjustments during the season (Joern, 1982; Parmenter *et al.*, 1991; Bonnet *et al.*, 1997). Grasshopper biodiversity is not only considered to be a product of the evolution of grassland ecosystems; a close relationship is also found between grasshopper biodiversity and the health of grassland ecosystems (Guo *et al.*, 2006).

Hence, the present study focuses on orthopteran diversity and abundance in coal mine spoils of different ages to elucidate the recolonisation patterns of grasshoppers and crickets following anthropogenic disturbances caused by surface mining activities. Information related to insect recolonisation and successional patterns should be useful to land managers in the development of suitable strategies for reconstruction of disturbed ecosystems.

Materials and Methods

Study Site

Investigation of the diversity and abundance of insects belonging to the order Orthoptera was conducted at six coal mine dump sites of various ages (0, 2, 4, 6, 8 and 10 years) established from 2001 to 2011. The original vegetation is that of a tropical dry deciduous forest (Singh, 2012). Forty - six plant species were planted by the mining company at each dump site about 1.5 years after establishment of the mine dumps. The coal mine sites of Northern Coalfields Ltd., are situated at Singrauli and the adjoining border area lying between Uttar Pradesh and Madhya Pradesh in India (latitudes 23° 47' to 24° 12′ N and longitudes 81° 48′ to 82° 52′ E). The vegetation in the mine sites is dominated by *Eragrostis unioloides*, *Saccharum spontaneum*, *Bambusa bamboo*, *Euphorbia hirta*, *Acacia catechu*, *Acacia nilotica*, *Acacia mangium*, *Dalbergia sissoo* and *Prosopis juliflora*, plants (Singh, 2011, 2012).

Sampling Methods

The orthopteran populations were sampled from February to March, 2012 and again during October – December, 2012. Two main methods were used to record the diversity and abundance of orthopterans at the six mine sites. These included: (1) the visual scanning, and (2) the sweep netting, methods. In the visual scan method, a metal quadrat frame was used and, the number and diversity of orthopterans were recorded in the quadrats (area = 1 m^2, n = 125 per day per site) which were randomly placed on the ground surface, over a period of five days (n = 625 per site). The sweep netting method involved random sweeping (n = 20 per site) of the ground, bushes and shrubs to capture the orthopterans, by using an insect net. Samples were preserved in 75% alcohol and taken to the laboratory for sorting and identification to genus/species level. Identification of the orthopteran specimens was done with the help of experts from the Department of Zoology, Aligarh Muslim University.

Data Analysis

Species diversity (alpha and beta diversity) at each mine site was calculated according to the Shannon–Weiner and Whittaker index methods, respectively.

Changes in the overall orthopteran abundance with mine site rehabilitation was analysed by carrying out one-way analysis of variance (ANOVA) followed by Dunnett's and

Duncan's Multiple Range post hoc Tests (DMRT) ($p < 0.05$), tests for analysis of abundance and of alpha diversity, respectively. Variance followed by DMRT post-hoc test was also applied to analyse in the abundance of grasshoppers and crickets in the 0 - 10 year old sites. Since no pristine areas were available, the dump site established in 2001 (10 years old) was taken as the reference site for determination of beta diversity and for the Dunnett's post-hoc test.

The orthopteran diversity at different sites was compared using the rank abundance plot in which percentage cumulative abundance (log) was plotted against species rank.

All orthopteran species restricted to specific succession stages were classified as habitat specialists. All others consistently recorded in 2-10 year old sites were referred to as habitat generalists (Table. 1).

All statistical analyses were done by using SPSS (16.0) statistical package (SPSS Inc, Chicago, USA; 1997) and MS Excel 2007.

Results

Species diversity and abundance

A total of 21 orthopteran species belonging to 16 genera were recorded in this study. The five orthopteran families present comprised Acrididae (10 species and 8 genera), Pyrgomorphidae (7 species and 4 genera), Gryllidae (2 species, 2 genera), Eumastacidae and Tettigoniidae (1 species and 1 genus, in each case) (Table 1).

Abundance of the 21 orthopteran species showed significant variations at all the five mine sites (0-8 year old), relative to the reference site: *Acrida conica, Acrida exaltata, Gastrimargus africanus, Leva cruciata, Pyrgomorpha* sp., *Chrotogonus* sp., *Lepidogryllus* sp., *Chrotogonus armatus, Spathosternum prasiniferum, Gastrimargus musicus, Oxya fuscovittata, Atractomorpha psittacina Carnarvonella* sp., *Pterophylla* sp., *Metioche* sp., *Catantops pinguis, Atractomorpha crenulata, Chrotogonus trachypterus, Sphingonotus savignyi, Bryodema luctuosa, Oedaleus abruptus* (One-way ANOVA: F = 52.823; 21.798; 33.607; 24.252; 18.672; 16.725; 5.253; 12.851; 42.073; 14.896; 30.889; 37.003; 7.626; 11.808; 8.584; 9.339; 16.933; 13.384; 16.170; 18.617; 17.806, respectively, df = 5, 3749; $p < 0.001$ in each case) (Fig. 1 a-c).

Dunnett's Post hoc test revealed significantly lower abundance of *A. exaltata, G. africanus, L. cruciata, S. prasiniferum,* and *Pterophylla* sp. in the 0-6 year old sites ($p < 0.001$, in each case) relative to the reference site. The abundance of *A. conica, Pyrgomorpha* sp., *Chrotogonus* sp., *G. musicus, A. crenulata, C. trachypterus* and *S. savignyi* in the early-intermediate successional stages, (0 - 4 year old) was significantly lower ($p < 0.001$, in each case) relative to their abundance in the 10 year old site. In the newly established dump sites (0 - 2 year old), abundance of *C. armatus* and *C. pinguis* was significantly lower ($p < 0.001$, in each case) in comparison to that found in the reference site. However, *B. luctuosa, O. abruptus, Carnarvonella* sp, and *Metioche* sp. found in the 4 and 6 year old sites were completely absent in the reference site. The abundance of *O. fuscovittata* and *A. psittacina,* was significantly lower ($p < 0.001$, in each case) in all the five (0-8 year old) mine sites relative to the climax site. Both *A. exaltata* and *L. cruciata* exhibited lower abundance (respective significance values being $p < 0.01$ and $p < 0.05$) in the 8 year old site. Although the abundance of *Pyrgomorpha* sp. *Chrotogonus* sp., *A. crenulata, S. savignyi* and *G. musicus* was progressively higher on moving from 2 - to 8-year old sites, significantly lower values relative to the reference site were obtained only in the

Table-1: Orthopteran diversity, feeding guilds, habitat specificity and stages recorded in the 0-10 year old mine sites by using the visual scanning and sweep netting methods (H = Herbivores and D = Detritivores).

Family	Species	Habitat specificity	Feeding guild	Sampling methods			
				Visual Scanning		Sweep Netting	
				Nymphs	Adults	Nymphs	Adults
Acrididae	*Acrida conica*	Generalist	H	+	+	+	+
Acrididae	*Acrida exaltata*	Specialist	H	-	+	+	+
Acrididae	*Gastrimargus africanus*	Generalist	H	-	+	+	+
Acrididae	Spathosternum prasiniferum	Specialist	H	+	+	-	-
Acrididae	Gastrimargus musicus	Generalist	H	+	+	-	+
Acrididae	Oxya fuscovittata	Specialist	H	+	+	-	+
Acrididae	*Catantops pinguis*	Generalist	H	-	+	-	-
Acrididae	*Sphingonotus savignyi*	Generalist	H	+	+	-	+
Acrididae	*Bryodema luctuosa*	Specialist	H	+	-	-	-
Acrididae	*Oedaleus abruptus*	Specialist	H	+	+	-	+
Pyrgomorphidae	*Leva cruciata*	Generalist	H	+	-	+	+
Pyrgomorphidae	*Pyrgomorpha* sp.	Generalist	H	+	-	+	+
Pyrgomorphidae	Chrotogonus sp.	Generalist	H	+	+	+	+
Pyrgomorphidae	Chrotogonus armatus	Generalist	H	+	-	+	-
Pyrgomorphidae	*Atractomorpha psittacina*	Specialist	H	-	+	-	+
Pyrgomorphidae	*Atractomorpha crenulata*	Generalist	H	-	+	-	+
Pyrgomorphidae	*Chrotogonus trachypterus*	Generalist	H	-	+	+	+
Gryllidae	*Lepidogryllus* sp.	Generalist	D	+	+	+	+
Gryllidae	*Metioche* sp.	Specialist	D	+	+	+	+
Tettigoniidae	*Pterophylla* sp.	Specialist	H	+	-	+	-
Eumastacidae	*Carnarvonella* sp.	Specialist	H	+	-	+	-

case of the 2 - 4 year old sites. The abundance of *C. pinguis* was significantly lower in the 0-2 ($p < 0.001$) and 4 ($p < 0.01$) year old sites relative to the reference site. *Acrida conica, G. africanus, Pyrgomorpha* sp., *Chrotogonus* sp., *S. prasiniferum, G. musicus, Carnarvonella* sp., *Pterophylla* sp., *A. crenulata, S. savignyi* and *B. luctuosa,* did not demonstrate any significant differences in their abundance at the 8 year old dump site in comparison to the climax site. Significant differences were also not obtained in the abundance of *Lepidogryllus* sp., *C. armatus, C. pinguis* and *C. trachypterus* at the 6 and 8 year old sites. *Metioche* sp. and *O. abruptus* abundance did not vary significantly at the 0, 2 and 8 year old dump sites in comparison to the climax, 10 year old site. *Carnarvonella* sp. was recorded only in 4 and 6 year old sites. Since all the species were absent in the 0 year old dump site, the abundance of each revealed highly significant values ($p < 0.001$, in each case) with respect to that for the reference site.

While twelve orthopteran species were found to be generalist species progressively increasing in abundance in the 2-10 year old sites, an exception was *Lepidogryllus* sp. which did not show any specific pattern with increase in restoration.

There were nine habitat specialist orthopteran species. *Carnarvonella* sp., *Metioche* sp., *Bryodema luctuosa* and *Oedaleus abruptus* were found only in 4 - 6 year old sites which had intermediate level of disturbance. In contrast, *Acrida exaltata, Spathosternum prasiniferum, Oxya fuscovittata, Atractomorpha psittacina* and *Pterophylla* sp. were restricted to the maximally restored, 8 and 10 year old sites.

Alpha diversity increased with the age of the coal mine sites from 0 to 10 years (Fig. 2). One-way ANOVA indicates significant differences in the orthopteran alpha diversity at the five (2-10 year old) study sites ($F_{5, 24} = 344.465$, $p < 0.001$). The 4-10 year old mine sites showed a very gradual increase in alpha diversity. However, the DMRT post hoc test revealed highly significant differences between alpha diversity found in the 0 and 2 year old site in comparison to the 6 and 8 year old and the reference, sites. Significant differences in diversity were also obtained between the 0, 2 and 4 year old sites. No significant differences were obtained between 6, 8 and 10 year old sites.

Beta diversity was highest in the 4 and 6 year old sites and lowest in the 2 year old dump site, while there was no difference in the species composition of the 8 and 10 year old dump sites (Fig. 3). While grasshopper abundance and number of species showed a linear increase, (the curve was steep initially and more gradual in the late successional stages) in the case of crickets, both parameters demonstrated a decrease in the later, 8-10 year old mine sites (Fig. 4). One-way ANOVA of grasshopper abundance showed highly significant differences ($F_{5, 24} = 1198.843$, $p < 0.001$) in the 0-10 year old sites, although abundance of crickets demonstrated a lower significance value ($F_{5, 24} = 3.186$, $p < 0.05$). The DMRT post hoc test revealed significant differences in grasshopper abundance among the 0-10 year old sites, while the abundance of crickets showed significant differences between 0 and 2-6 year old sites. No significant differences were found between 2-10 year old sites (Fig. 4)

Rank abundance patterns revealed that lowest orthopteran diversity is found in the 2 year old site (the uppermost curve). There was overlap between the rank abundance curves obtained for the 4-10 year old sites (Fig. 5).

Discussion

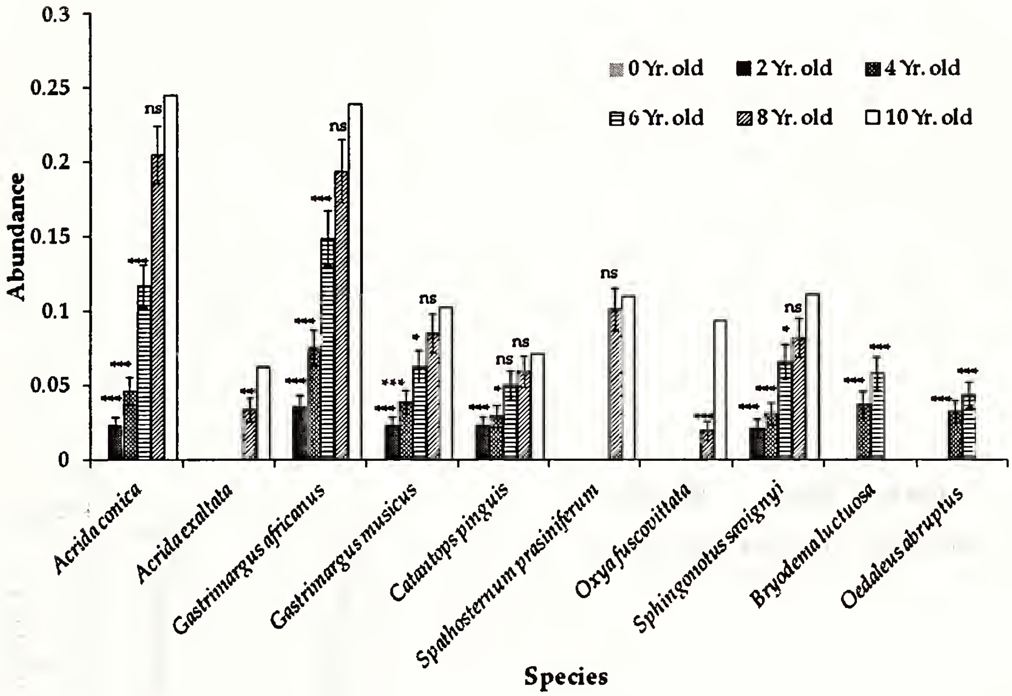
Our results reveal that grasshoppers are early colonisers of revegetated mine sites, since out of the 12 orthopteran species recorded at the 2 year old site, 11 species were of grasshoppers and only a solitary species of cricket (*Lepidogryllus* sp.) was found. Acrididae and

Pyrgomorphidae were species rich families dominant at the mine sites. While *G. africanus* remained consistently abundant in the 2-10 year old spoils, *A. conica* abundance increased gradually, reaching peak values only in the 10 year old, climax, successional stage (Fig. 1). Three species of grasshoppers, *Carnarvonella* sp., *B. luctuosa* and *O. abruptus* preferred habitat conditions prevalent in 4 and 6 year old dump sites and were totally absent in the late successional stages. Some grasshopper species appear to be highly sensitive to environmental disturbances caused due to mining activities. Thus, *A. exaltata, O. fuscovittata* and *Pterophylla* sp. appear to be late- colonising grasshopper species, arriving much later i.e. in the almost restored, 8 year old mine site, onwards. Our results thus support earlier studies, carried out in rangelands, which show that grasshopper species assemblages are highly sensitive to the level of disturbance (Kemp *et al.*, 1990).

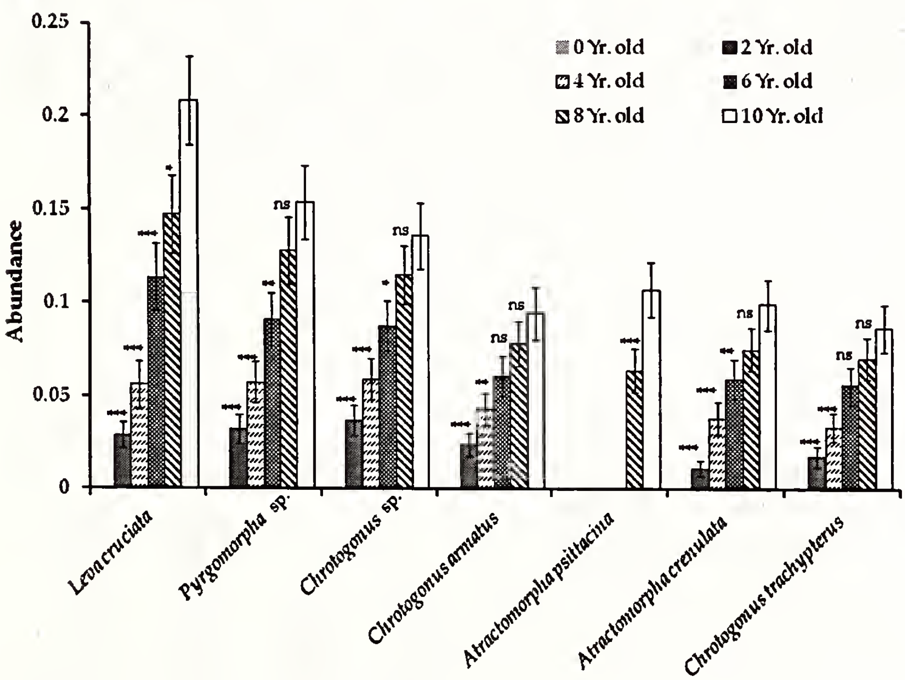
Orthopterans were totally absent in the newly established mine sites. However, alpha diversity of orthopterans progressively but gradually increased (although not significantly) in the 4-10 year old sites. Beta diversity exhibited a gradual increase, reaching highest values in the 4-6 year old sites, there being no difference in orthopteran diversity between the 8 and 10 year old sites. Alpha diversity and rank abundance patterns indicate that orthopteran diversity is low in the highly disturbed site (2 year old) but after increasing sharply in 4 year old site, at intermediate levels of disturbance does not increase significantly in the more disturbed, 6-10 year old sites. The lack of a clear pattern in rank abundance curves obtained for 4-10 year old sites may be due to the fact that while the alpha diversity of orthopterans does not differ significantly between sites with intermediate and low levels of disturbance, abundance levels are significantly higher in the less disturbed sites. Secondly, the number of species of crickets (i.e. decomposers) decreased while those of herbivorous grasshoppers increased with increase in mine site rehabilitation age. Moreover, while some species are habitat specialists, characteristic of specific successional stages (either with low or high disturbance levels), others are generalists which gradually increase in abundance along the descending disturbance gradient.

The abundance and diversity of crickets (decomposer feeding guild, Gullan and Cranston, 2000) showed a steep increase initially but decreased in the 8-10 year old mine sites. While *Metioche* sp. showed an increasing abundance trend in the 4 to 6 year old mine sites and was absent in later stages, *Lepidogryllus* sp. did not demonstrate any abundance pattern in the 2-10 year old sites. Thus, decomposers are found to be more abundant in the early successional stages and gradually decrease and give way to the herbivores in the late successional 8 year old site and the climax, 10 year old mine site. Earlier studies on newly abandoned arable land, meadows with large mammal grazing pressure and protected semi-natural steppe meadow, report orthopteran assemblages to be more stable on the undisturbed and intermediate disturbance level sites (Baldi and Kisbenedek, 1997). In the complete absence of significant grazing by mammalian herbivores at the mine sites, the herbivorous grasshoppers and decomposer crickets provide an important ecological pathway for energy flow and nutrient cycling.

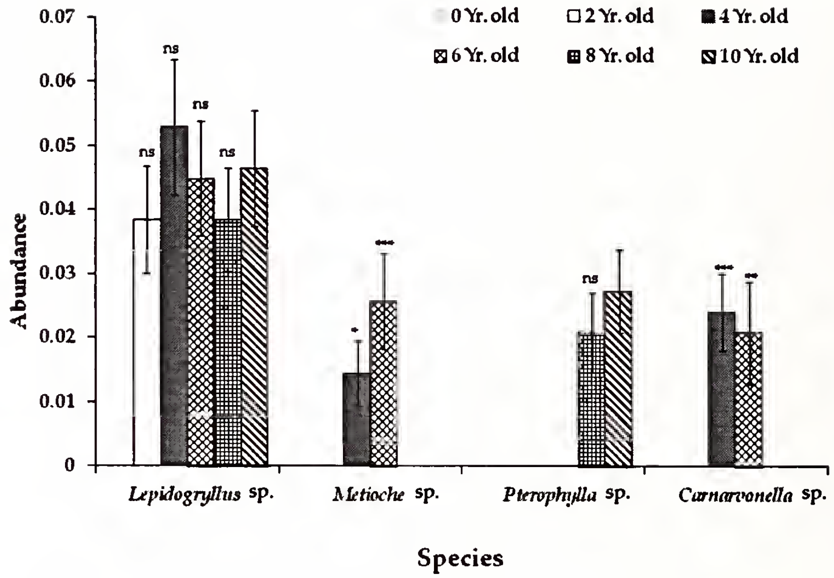
Being a major source of food for predatory arthropods (Schmitz, 2008), orthopteran species may influence other organisms during the re-colonisation process. They are also important components of the food chain for many insectivorous birds and mammals (Capinera *et al.*, 1997; Mayya *et al.*, 2005), Alteration of orthopteran population dynamics is expected to affect several trophic levels in the food chain (Capinera *et al.*, 1997).


0 Yr. old
2 Yr. old
4 Yr. old
6 Yr. old
8 Yr. old
10 Yr. old
Abundance
Acrida conica
Acrida exaltata
Gastrimargus africanus
Gastrimargus musicus
Catantops pinguis
Spathosternum prasiniferum
Oxya fuscovittata
Sphingonotus savignyi
Bryodema luctuosa
Oedaleus abruptus
Species

1 (a)


0 Yr. old
2 Yr. old
4 Yr. old
6 Yr. old
8 Yr. old
10 Yr. old
Abundance
Leva cruciata
Pyrgomorpha sp.
Chrotogonus sp.
Chrotogonus armatus
Atractomorpha psittacina
Atractomorpha crenulata
Chrotogonus trachypterus
Species

1 (b)



1 (c)

Fig.1: Abundance of orthopteran species belonging to different families: (a) Acrididae, (b) Pyrgomorphidae, (c) Gryllidae, Tettigoniidae and Eumastacidae, in coal mine spoils established in 2011 (0 year old), 2009 (2 year old), 2007 (4 year old), 2005, (6 year old), 2003 (8 year old) and 2001 (10 year old, reference site). One-way ANOVA followed by Dunnett's post hoc test: * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$, ns- Not significant.

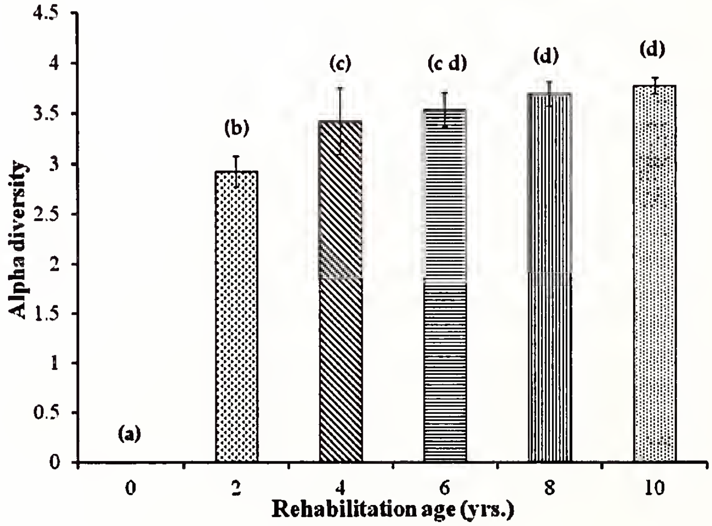


Fig.2: Alpha diversity of orthopteran species in 0 to 10 year old coal mine sites (established in 2011, 2009, 2007, 2005, 2003 and 2001, respectively). One way ANOVA followed by Duncan's Multiple Range Test (DMRT) ($p < 0.05$) were used to compare the calculated orthopteran alpha diversity at different coal mine sites. Different letters denote significant differences ($p < 0.05$) among orthopteran alpha diversity at different sites (0-10 year old).

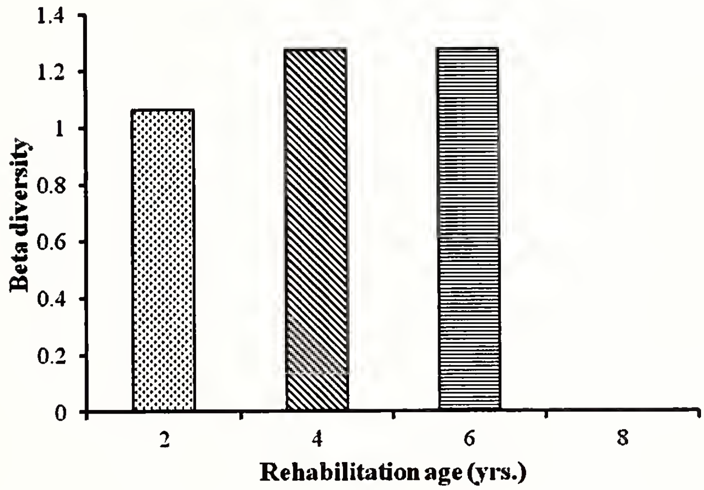


Fig.3: Beta diversity of orthopteran species in 2-8 year old coal mine sites (established in 2009, 2007, 2005 and 2003, respectively).

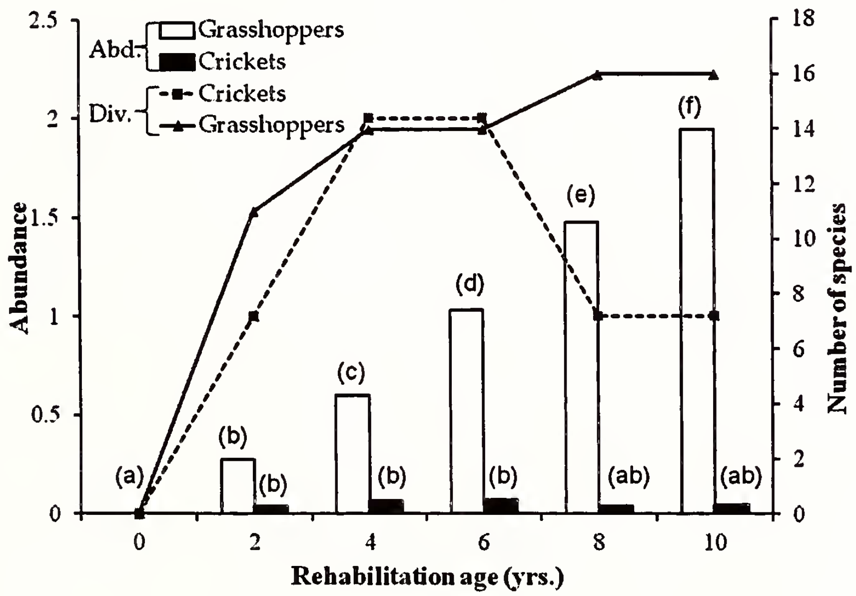


Fig.4: The diversity and abundance of grasshoppers and cricket species in 0-10 year old coal mine sites (established in 2011, 2009, 2007, 2005, 2003 and 2001, respectively).

□ = Abundance of grasshoppers, ■ = Abundance of crickets,

—▲— = Diversity of grasshoppers, —■— = Diversity of crickets

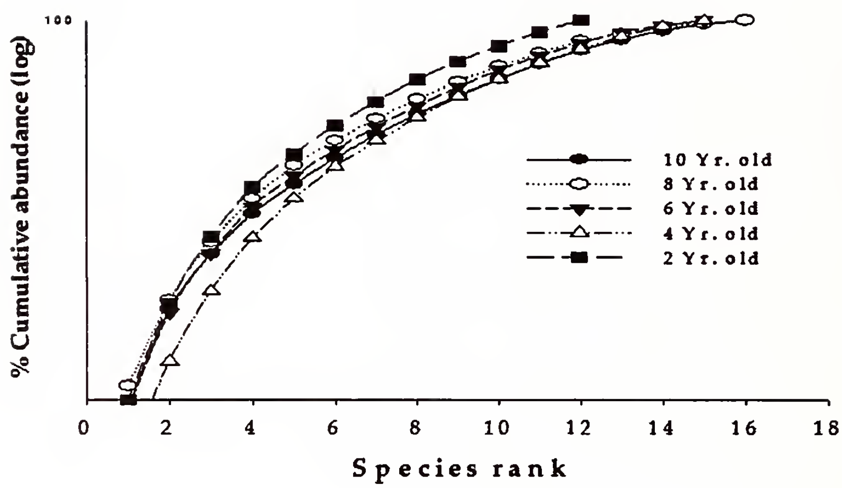


Fig.5: Species rank abundance plot of orthopteran community in 2 to 10 year old coal mine sites (established in 2009, 2007, 2005, 2003 and 2001, respectively).

The results of the present study clearly demonstrate a strong relationship between anthropogenic disturbances due to mining activities and orthopteran assemblage compositions in mine sites of different ages. Grasshopper diversity and abundance varied linearly with degraded ecosystem rehabilitation, suggesting the important role of grasshoppers in food webs operating in the mine sites. Since grasshopper assemblages are documented to show stronger differentiation among disturbed sites not evident even on the basis of floristic data (Andersen *et al.*, 2001), the abundance patterns of grasshoppers, particularly those of habitat specialists, may be of significance in the evaluation of restoration progress in degraded ecosystems.

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